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Briefing: Accounting for uncertainty in aggregated emissions - Impact estimates

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1 Context & challenge

Sector policy experts are developing emissions-impact estimates for a large number of climate change policies. For each policy, sector teams are asked to provide:

- A best estimate (most likely outcome)
- A plausible best-case estimate (optimistic but realistic)
- A plausible worst-case estimate (pessimistic but realistic)

From this, an overall uncertainty estimate, or confidence level is to be determined for the portfolio of policies. A simple approach to this would be achieved by summing the total best and worst estimate cases across all policies and calculate the difference to provide a single numerical range value. That is,

$$\sum(\text{ plausible worst-cases}) - \sum(\text{ plausible best-cases}).$$

This would allow statements of the following form to be made:

"Based on expert estimates the total emissions reduction could plausibly go from 10 $MtCO_2e$ to 50 $MtCO_2e$, with a range of 40 $MtCO_2e$"

While this gives a basic measure of spread, it has two major limitations:

- It assumes all policies meet their respective extremes simultaneously, which is highly unlikely.
- It does not convey how likely any given value within the range is – it's a bounding box, not a probability distribution.

Thus, a more robust way is needed to present a meaningful range and confidence interval for the aggregated emissions reductions.

2 Proposed approach

A Monte Carlo simulation is well-suited for this type of uncertainty analysis. It improves upon the simple range aggregation method by:

- Capturing the combined effect of many policies without assuming extremes occur simultaneously.
- Providing a probabilistic estimate that better represents likely outcomes.
- Allowing sensitivity testing (e.g. exploring the impact of policy correlations if relevant)

The key steps for conducting the Monte Carlo simulation are:

1. Define probability distributions – Each policy's emissions impact is modelled using a probability distribution based on sector team inputs. Pragmatically, a triangular distribution (peaked at the best estimate, with plausible best/worst case as the range) is a practical and transparent choice given limited data.
2. Run simulations – Random values are drawn from each policy's distribution and aggregated. This process is repeated potentially thousands of times to build a distribution of total emissions outcomes.
3. Analyse the output – The resulting distribution of aggregated policy impacts allows us to:
   - Derive a probable range (e.g. 10th – 90th percentile) rather than an extreme max-min spread of the simplified approach.
   - Identify a central estimate (e.g. the median or mean of the distribution).
   - Calculate confidence intervals (e.g. 95% confidence that total reductions fall within a specific range).

It is important to consider methodological choices before undertaking the analysis, including confidence in the policy estimates that are made by the experts, probability distributions chosen and treatment of policy dependencies.

The Monte Carlo simulations can be implemented using widely available tools, for example, Python, R, or Microsoft Excel (with appropriate plug-ins or add-ins).

Following the analysis of the outputs of the Monte Carlo simulations, specific commentary can be made on emissions-impact estimates for the full policy package, ensuring clarity in the communication of uncertainty.

3 Dependence on expert inputs

An important caveat in the robustness of the Monte Carlo results is that the method depends entirely on the quality of the underlying inputs. Since the method uses expert-provided worst-case, best estimate, and best-case values, any biases, inconsistencies, or overly optimistic/pessimistic assumptions will be carried through to the results. It is therefore essential to:

- Encourage sector teams to provide realistic and well-considered bounds.

- Be clear that the results reflect expert judgement about what could happen, rather than measured variability based on observed data.
- Revisit and refine inputs as more data or evidence becomes available.

Outputs from Monte Carlo simulation

The Monte Carlo simulation approach would allow statements of the following forms to be made:

In relation to central estimates (median or mean):

"The median estimated emissions reduction from the policy package is 29 $MtCO_2e$."

For confidence intervals:

"We estimate with 95% confidence that total emissions reductions will fall between 18 and 43 $MtCO_2e$."

For percentile ranges:

"The 10^{th}–90^{th} percentile range for total emissions reduction is 20 to 40 $MtCO_2e$, reflecting where most outcomes are concentrated."

For risk-based statements:

"There is less than a 5% chance that the policy package will achieve less than 20 $MtCO_2e$ in emissions reductions."

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